MEDINFO 2019: Health and Wellbeing e-Networks for All
L. Ohno-Machado and B. Séroussi (Eds.)

doi:10.3233/SHTI190320

A Model Driven Approach to the Design of a Gamified e-Learning System for Clinical Guidelines

Job N. Nyameino[a,b], Fazle Rabbi[c], Khalid A. Mughal[a], Martin C. Were[d,e,b] , Yngve Lamo[c]

[a] *Department of Informatics, University of Bergen, Bergen, Norway,*
[b] *Institute of Biomedical Informatics, College of Health Sciences, Moi University, Eldoret, Kenya*
[c] *Department of Computing, Mathematics, and Physics, Western Norway University of Applied Sciences, Bergen Norway.*
[d] *Department of Biomedical Informatics, Vanderbilt University Medical Center, Nashville, TN, USA*
[e] *Vanderbilt Institute for Global Health, Vanderbilt University Medical Center, Nashville, TN, USA*

Abstract

Clinical practice guidelines (CPGs) are indispensable in the practice of evidence-based medicine. However, the cost of effective CPG dissemination strategies is prohibitive and not cost-effective. Therefore, scalable strategies using available technology are needed. We describe a formal model-driven approach to design a gamified e-learning system for clinical guidelines. We employ gamification to increase user motivation and engagement in the training of guideline content. Our approach involves the use of models for different aspects of the system, an entity model for the clinical domain, a workflow model for the clinical processes and a game model to manage the training sessions. A game engine instantiates a training session by coupling the workflow and entity models to automatically generate questions based on the data in the model instances. Our approach is flexible and adaptive as it allows for easy updates of the guidelines, integration with different device interfaces and representation of any guideline.

Keywords:

Practice Guideline; Statistical Model; Computer Games

Introduction

Over the past three decades, the concept of evidence-based medicine has become the pre-eminent paradigm in informing clinical decision making. Evidence-based medicine is the conscientious, explicit, and judicious use of best evidence in making decisions about the care of individual patients [1]. The volume of published medical literature is immense and it is practically impossible for a clinician to read and appraise all the available evidence. This has led to efforts to systematically appraise the literature and provide summaries of the evidence in the form of clinical guidelines that can be more easily consumed by healthcare workers.

Clinical guideline are statements that include recommendations intended to optimize patient care. They are informed by a systematic review of evidence and an assessment of the benefits and harms of alternative care options [2]. Guidelines serve a variety of functions such as improving effectiveness and quality of care, decreasing variations in clinical practice, and decreasing costly and preventable mistakes and adverse events [3].

Development of clinical guidelines is not by itself enough. For a health system to derive value from available guidelines, effective dissemination and implementation strategies have to be employed to facilitate the integration of the guideline recommendations in clinical practice. Dissemination refers to the methods by which guidelines are made available to potential users, while implementation refers to ensuring that the users act on the recommendations [4]. Currently, there is no consensus on the most effective dissemination strategies although the use of a multifaceted dissemination approach has been found to be more effective than single interventions [5,6]. Further, the passive distribution of printed educational material on care guidelines was found to be less effective than active approaches such as educational outreaches [7].

Despite the observed effectiveness of educational outreaches as a dissemination strategy, these often require significant financial and human resource commitment that might not be readily available in low resource settings. For example, the Emergency, Triage, Assessment and Treatment plus Admission care (ETAT+) course is a 5.5 day course developed in Kenya to train healthcare workers on the guidelines for emergency paediatric care. During its initial implementation, the cost of the whole training for 32 participants using 5 facilitators cost $5000 for facilitators and meals, not to mention the cost of having providers away from work and the often associated additional costs for trainings provided at a conference facility [8]. This is neither scalable nor sustainable.

To address these dissemination challenges, new, innovative and cost-effective strategies that leverage contemporary technologies need to be employed [9]. A study conducted in Kenya showed that ownership of mobile phones among healthcare workers was nearly universal with 98.6% of respondents reporting mobile phone ownership and 75% reporting using their mobile phones to access work-related information [10]. This provides an opportunity to use the mobile electronic platforms to conduct educational outreach in a scalable, cost effective and automated fashion.

In this paper, we describe a formal model driven approach to the design of a gamified elearning system for clinical guidelines. Gamification is the use of game design elements in non-game contexts [11]. It uses game-based mechanics, aesthetics and thinking to engage people, motivate action, promote learning and solve problems [12]. The term "Gamification" is relatively new and has been used to describe the use of game-based concepts and techniques outside recreational activities, with the goal of increasing the motivation and engagement of the participants and improving the results. The benefits of gamification are an increase in motivation and engagement, which can be applied in education or work-related contexts.

To be effective, gamification of guidelines would require flexibility and adaptiveness as the users have various learning styles. In this paper, we describe an innovative model-driven approach for dissemination of a gamified eLearning system for clinical guidelines, and the resultant prototype of this system.

Methods

Model Driven Engineering

To design our gamified training system, we aim to use a model driven engineering (MDE) approach. MDE is a system development paradigm that promotes the use of models as the primary artefacts that drives the whole development process [13]. An MDE approach provides several advantages that we leveraged for our purposes. First, it improves communication by exploiting abstraction and domain-specificity which can target different audiences. Secondly, MDE facilitates separation of the specification of system functionality from the specification of the implementation of that functionality on a specific technology platform. This is especially significant since technology platforms are in a constant state of flux, changing frequently in response to business needs and technological development. By adopting MDE, the business logic of the system and its application technologies can evolve independently of each other. Implementations execution is mad easier by abstraction on different platforms while maintaining the structure and behaviour of the system.

In MDE, models are specified using modelling languages. A modelling language is defined by a metamodel (a model of models) and is a set of all possible models that conform to this metamodel [14]. There are two types of modelling languages, namely: (1) General Purpose Modelling Languages (GPLs) and (2) Domain-Specific Modelling Languages (DSLs). GPLs, as the name suggests, tend to be general and with poor support for domain-specific notation. Conversely, DSLs are tailored to a specific application domain that offers appropriate notations and abstractions. DSLs are thus more expressive and easier to use with concomitant gains in productivity and maintenance costs [14]. The abstract syntax of the DSL is a conceptualization of all the concepts, abstractions and relations underlying the domain represented as a model which acts as the metamodel of the modelling language.

A metamodel architecture introduces a generic pattern of metamodelling hierarchy in which models at each level are specified by a modelling language at the level above it and conform to the corresponding metamodel of the language. Figure 1 illustrates a metamodelling hierarchy where a model M_i at a certain level *i* (e.g. M_0, M_1 etc) conforms to a metamodel M_{i+1} at the level above until a model M_j has itself as metamodel, called a reflexive model.

However there are several aspects to design in a software model which requires the co-ordination of multiple models. These aspects include the design of information systems that have several sub-systems that communicate with each other. Rabbi et al. proposed to use an integration of multiple metamodeling hierarchies to co-ordinate various aspects of a system [15]. Our approach is also based on the idea of coordination of multi-metamodeling hierarchy where we integrate entity models, workflow models and models that represents the gaming aspects of a training program. Below, we describe each of these models and their integration within our model.

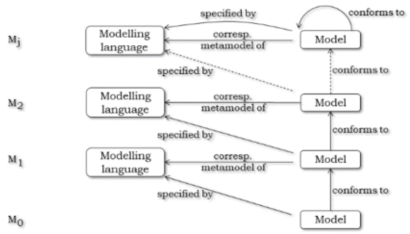

Figure 1:Generic pattern: modelling languages and metamodels [16]

Entity Model

In order to conceptualize the clinical encounters, we define an entity model relevant to the medical domain. This involves identification of the significant concepts in the clinical encounter, with a clear delineation of their attributes and relations (Figure 2). The figure shows a constraint [preCondition] implied over the relations on patient, diagnosis, and treatment. The semantic of the constraint specifies that "for every treatment, patients' diagnosis needs to be confirmed".

This clinically-relevant entity model forms the data model from which the game engine populates instances in the workflow model (see below).

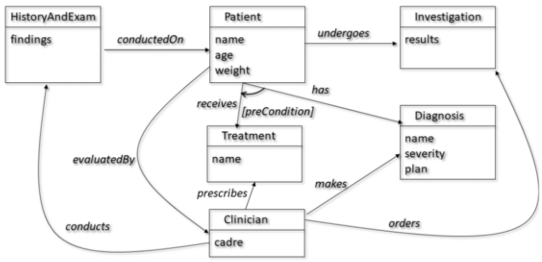

Figure 2: A simplified entity model of the clinical encounter domain

Workflow Model

Once the entity model is defined, we define the workflow model. Clinical practice guidelines can run into tens or hundreds of pages and are usually summarized in algorithmic flow charts that show the process of treatment for a given scenario. Our approach leverages the flowchart structure of the guideline summaries to design our workflow model.

Figure 3 demonstrates the use of the metamodelling hierarchy to depict the flow of tasks during a clinical encounter using an use case of asthma. At level M_2, we have a meta-metamodel showing the abstraction of how tasks flow from one to the next. Level M_1 shows a generic abstraction of the process of a clinical encounter from the initial assessment, diagnosis, treatment and evaluation of the treatment, after which the treatment can be repeated or the patient reassessed afresh to review the diagnosis. Finally, at level M_0, we show an instance of the recommended flow of tasks when treating a child with asthma.

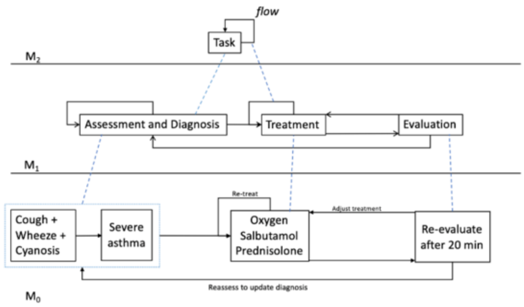

Figure 3: Workflow model showing the flow of tasks during a clinical encounter

Game Model

The design of gamified e-learning systems should be undertaken in view of the core concepts of games i.e. goal-oriented activities with reward mechanisms and progress tracking [17]. To become familiar with guideline content, learners need to know how to treat the different aspects of a disease condition as outlined within the guideline. Game models use reward mechanisms and progress tracking aids in order to increase the users engagement and motivation.

The game engine in our model automatically generates questions from the entity and workflow models to instantiate a training module. The questions are categorized according to the learner's skill level (beginner, intermediate, advanced). The model also specifies a *learner profile* that tracks the learner's activities. Figure 4 shows the model for the game engine.

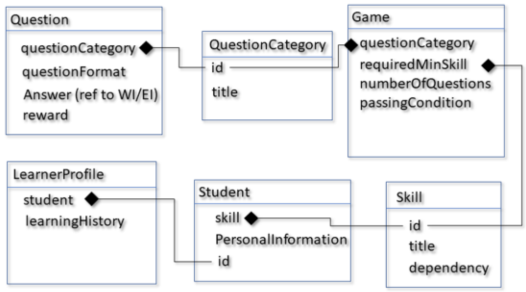

Figure 4: Game model

Integrated Training Model

The training model is built by coupling and coordinating the entity and workflow models discussed above based on the principles introduced by Rabbi et al [15]. The states of the training module (*TM*) are defined by a set of elements that include a pair of workflow instance (*WI*) and an entity instance (*EI*): $TM_i = <EI_i, WI_i>$. This coupling of models is illustrated in Figure 5. Here, we show a part of the entity model with values from a given scenario where based on the *History & Examination* findings, a *Diagnosis* of Severe Asthma is made and its *Treatment* specified. The flow of how this process should happen is shown in the workflow model.

The game engine instantiates a training session by generating questions based on the entity model and workflow model. For example, it could initially generate a scenario based on the patient details and history and examination findings and ask what the diagnosis is. If answered correctly, it will move on to the next task and ask about the treatment. A training session is composed of a sequence of training modules and is evolved from the initial state of a training flow and progresses based on the answer provided by the user.

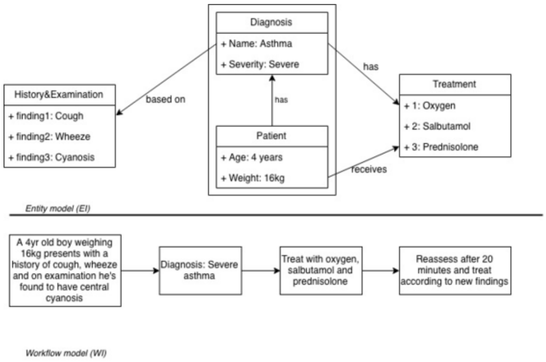

Figure 5: Coupled entity and workflow models

Figure 6 illustrates the idea of the progression of the states of training session. Depending on the answer given by the user a game engine consults with the training flow and evolves the state of the training session. We use the diagram predicate approach for representing the status of our training modules and their transformation [18]. Two annotations **< Enabled >** & **< Disabled >** are used to represent the current status of the training modules. A training module TM_0 when annotated with the **< Enabled >** predicate indicates that the training module is currently active and is being considered for training. Once TM_0 is completed successfully, it is disabled and TM_1 is enabled. This continues until the training session is over. If a wrong answer is given the training module is repeated with hints until the correct answer is given.

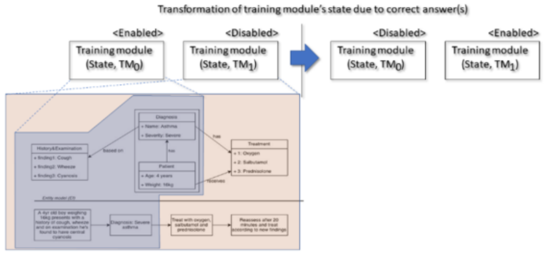

Figure 6: Progression of the states of the training session

Model Based Analysis

Since our approach is based on models, there are lot of opportunities to make sure the guideline scenarios being represented by the models are correct. We use model transformation rules to control the flow of training sessions. Transformation rules are often used in an MDE approach to encode the knowledge of a transformation that can be analyzed. This allows us to perform reasoning over the models. This means anylizing the models for validity, semantic consistencies and inconsistencies. For example we can perform reasoning over the models to answer the following questions:

- Are there sufficient number of questions to run a training session?
- Classify the questions over different stages e.g., identify questions that belong to the 'Diagnosis and Assessment' stage of a guideline training.
- Can we use a computer system such as that one by Alloy to randomly produce a scenario and generate questions [19]? How can we make sure that the scenarios are valid instance of a guideline?
- If there are certain number of questions to be asked in a session, what informaiton are common among the questions?
- How can we find out an order of the questions that complies with the order of the guideline?

We have applied DPF constraint checking [18] to find answer to some of the reasoning questions mentioned above. The fundamental idea of DPF constraint checking is based on the principle of category theory. Several techniques have been studied in [20] to produce valid DPF instances that satisfies the constraints in the metamodel. However, the technique has not been applied for multilevel metamodeling. In future, we will enhance the technique presented in [20] and use Alloy to randomly produce valid guideline scenarios.

Modular Architecture

The vision of this approach is to develop general components that can be utilized in the development of training programs for different guidelines. Figure 7 shows the overall architecture of our system. The training management module contains reusable elements that control the flow of questions in a training session and keeps usage logs. The entity models are the elements that should differ from one training program to another, however their metamodel should remain the same. The game engine components of the architecture is responsible for integrating with other systems. As an example, in this architecture, we show how the game engine is being interfaced with the dialogflow framework of Google assistant and the React framework [21] [22].

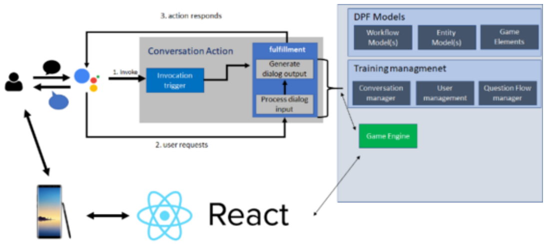

Figure 7: Overall architecture of the MDE approach

Learning Analytics

In our implementation, we utilize learning analytics for providing better training environment for the user. The training program records the history of training sessions. Therefore, we can perform some analysis over the training data such as whether the questions are too easy or too difficult for learners. While presenting questions to the user, the system does not only know how many questions the user has correctly answered, but also the time taken by the user to finish a training session. This allows the trainers to adjust the difficulty of the training sessions. Learning analytics are to identify the part of a training session that students often struggle with and the outcome of a session. A dashboard for the trainers with visualization can then be used to show the progress of the trainees. The goal is to make the training programs adaptable for various levels of difficulty to increase learners' interest to the sytem for practicing use of guidelines. This adaptability cannot be achieved without use of the learning analytics. The application of MDE enables achievement of this requirement as all the training programs share an abstraction. Building a visualization is therefore achievable in general across different training modules. With this model, machine learning techniques can also be applied to automatically adjust the difficulty of training sessions.

Results

The approach we describe in this paper has been materialized through a prototype tool for the gamification of CPGs. The specific use-case we employ is based on asthma care guidelines [23]. The model based approach for game engine allows us to develop and/or customize a new training program by making changes in the model. The MDE approach for modularizing different components of the system and its seperation from the user interaction allows us to integrate with various frameworks of user interaction such as Google's Dialogflow and React Framework [21] [22]. Since the model for the guideline and gamification remains the same, adding various techniques such as mobile-based interaction and voice-based interaction requires very small effort. With the prototype tool we show the potential of using MDE approach supporting different learning style of students. With the proposed idea of applying learning analytics for providing adaptive training to the trainee will provide better training results.

One indirect result of our approach is the support for innovating technologies. The generalized game engine can be integrated with new platforms such as Amazon Echo, integration with IoT devices that are used in clinical setup e.g., robot doll patients.

Another result is the support for ICT research in the training of practitioners. Data science and machine learning techniques can be used to understand the learning pattern of students and adapt them for better learning outcome.

Discussion

This work presents a model-driven approach to the design of an elearning system for clinical guidelines. Most current research on the use of gamification in medical education is focused on the effect of the educational games in knowledge and skill acquisition and on their acceptability. Akl et al present an educational game for teaching clinical practice guidelines to internal medicine residents [24]. In their description, domain experts developed multiple choice questions based on clinical guidelines which were then uploaded into the system via a question editor. This approach is inefficient in both the manual development of questions, and in the static nature of available questions. Our model-based approach allows for questions to be generated automatically, and the learner analytics platform helping to adapt the questions to the strengths and weaknesses of the learner. The automation of different aspects of the system means that once it is set up, it will require minimal resources to maintain, hence saving costs.

Our modular approach provides several other advantages. It makes it easier to update guidelines as only parts of the entity and workflow models change while the rest of the system remains the same. It is flexible also enough to allow for integration with various devices supporting different means of user-interaction and the abstraction of the clinical processes allows for the representation of any guideline. Further, the use of gamification will potentially enhance the learning experience by increasing student engagement with the learning material as reported in several studies [11,17,25].

There are a number of limitations to the gamified elearning system we describe in this work. First, full training of guideline content that requires the learning of some physical skills - such as performing cardiopulmonary resuscitation (CPR) – cannot be fully performed using our system as our system can only train on guideline content that do not require hands on training. Secondly, dissemination and implementation of clinical guidelines is a continuum that cannot be separated. Our system only addresses the dissemination half of that continuum and is not enough to bridge the gap between recommended and actual practice. Finally, there are several non-technological barriers to adherence to clinical practice guidelines, [26] and our system only addresses two of these barriers: lack of awareness and lack of familiarity with the guidelines.

In the near future, we plan to enhance our prototype tool for the development of other clinical guidelines. We wil also evaluate the acceptability and effectiveness of the proposed technique as a dissemination strategy for clinical guidelines within resource-limited settings.

Conclusions

We set out to design a gamified e-learning system for the training of clinical practice guideline content. Our approach allows for a flexible, adaptive and potentially cost-effective e-learning system.

Acknowledgements

This work was supported in part by the NORHED program (Norad: Project QZA-0484). The content is solely the responsibility of the authors and does not necessarily represent the official views of the Norwegian Agency for Development Cooperation. All authors report no conflict of interest.

References

[1] D.L. Sackett, Evidence-based medicine, *Seminars in Perinatology*. **21** (1997) 3–5. doi:10.1016/S0146-0005(97)80013-4.

[2] Institute of Medicine (US) Committee on Standards for Developing Trustworthy Clinical Practice Guidelines, Clinical Practice Guidelines We Can Trust, National Academies Press (US), Washington (DC), 2011. http://www.ncbi.nlm.nih.gov/books/NBK209539/ (accessed August 24, 2017).

[3] T. Kredo, S. Bernhardsson, S. Machingaidze, T. Young, Q. Louw, E. Ochodo, and K. Grimmer, Guide to clinical practice guidelines: the current state of play, *Int J Qual Health Care*. **28** (2016) 122–128. doi:10.1093/intqhc/mzv115.

[4] L. Thomas, Clinical practice guidelines, *Evid Based Nurs*. **2** (1999) 38–39. doi:10.1136/ebn.2.2.38.

[5] J.M. Grimshaw, H.J. Schünemann, J. Burgers, A.A. Cruz, J. Heffner, M. Metersky, and D. Cook, Disseminating and Implementing Guidelines, *Proc Am Thorac Soc*. **9** (2012) 298–303. doi:10.1513/pats.201208-066ST.

[6] J.M. Grimshaw, R.E. Thomas, G. MacLennan, C. Fraser, C.R. Ramsay, L. Vale, P. Whitty, M.P. Eccles, L. Matowe, L. Shirran, M. Wensing, R. Dijkstra, and C. Donaldson, Effectiveness and efficiency of guideline dissemination and implementation strategies, *Health Technol Assess*. **8** (2004) iii–iv, 1–72.

[7] J.M. Grimshaw, L. Shirran, R. Thomas, G. Mowatt, C. Fraser, L. Bero, R. Grilli, E. Harvey, A. Oxman, and M.A. O'Brien, Changing provider behavior: an overview of systematic reviews of interventions, *Med Care*. **39** (2001) II2-45.

[8] G. Irimu, A. Wamae, A. Wasunna, F. Were, S. Ntoburi, N. Opiyo, P. Ayieko, N. Peshu, and M. English, Developing and introducing evidence based clinical practice guidelines for serious illness in Kenya, *Archives of Disease in Childhood*. **93** (2008) 799–804. doi:10.1136/adc.2007.126508.

[9] B. Djulbegovic, and G.H. Guyatt, Progress in evidence-based medicine: a quarter century on, *The Lancet*. **390** (2017) 415–423. doi:10.1016/S0140-6736(16)31592-6.

[10] N. Muinga, B. Sen, P. Ayieko, J. Todd, and M. English, Access to and value of information to support good practice for staff in Kenyan hospitals, *Glob Health Action*. **8** (2015). doi:10.3402/gha.v8.26559.

[11] S. Deterding, M. Sicart, L. Nacke, K. O'Hara, and D. Dixon, Gamification. Using Game-design Elements in Non-gaming Contexts, in: CHI '11 Extended Abstracts on Human Factors in Computing Systems, ACM, New York, NY, USA, 2011: pp. 2425–2428. doi:10.1145/1979742.1979575.

[12] K.M. Kapp, The gamification of learning and instruction: game-based methods and strategies for training and education, John Wiley & Sons, 2012.

[13] I. Kurtev, J. Bézivin, F. Jouault, and P. Valduriez, Model-based DSL Frameworks, in: Companion to the 21st ACM SIGPLAN Symposium on Object-Oriented Programming Systems, Languages, and Applications, ACM, New York, NY, USA, 2006: pp. 602–616. doi:10.1145/1176617.1176632.

[14] A. Rodrigues da Silva, Model-driven engineering: A survey supported by the unified conceptual model, *Computer Languages, Systems & Structures*. **43** (2015) 139–155. doi:10.1016/j.cl.2015.06.001.

[15] F. Rabbi, Y. Lamo, and W. MacCaull, Co-ordination of Multiple Metamodels, with Application to Healthcare Systems, *Procedia Computer Science*. **37** (2014) 473–480. doi:10.1016/j.procs.2014.08.071.

[16] A. Rutle, Diagram predicate framework: A formal approach to MDE, The University of Bergen, 2010. https://bora.uib.no/handle/1956/4469 (accessed November 7, 2016).

[17] D. Strmečki, A. Bernik, and D. Radošević, Gamification in E-Learning: Introducing Gamified Design Elements into E-Learning Systems, *Journal of Computer Science*. **11** (2016) 1108–1117. doi:10.3844/jcssp.2015.1108.1117.

[18] F. Rabbi, Y. Lamo, I.C. Yu, and L.M. Kristensen, WebDPF: A web-based metamodelling and model transformation environment, in: 2016 4th International Conference on Model-Driven Engineering and Software Development (MODELSWARD), 2016: pp. 87–98.

[19] D. Jackson, Alloy: a lightweight object modelling notation, *ACM Transactions on Software Engineering and Methodology*. **11** (2002) 256–290. doi:10.1145/505145.505149.

[20] X. Wang, Towards Correct Modelling and Model Transformation in DPF, (2016).

[21] Google, Dialogflow, *Dialogflow*. (n.d.). https://dialogflow.com/ (accessed November 23, 2018).

[22] React – A JavaScript library for building user interfaces, (n.d.). https://reactjs.org/index.html (accessed November 23, 2018).

[23] MoH, Kenya, Basic Paediatric Protocols, 2016.

[24] E.A. Akl, R. Mustafa, T. Slomka, A. Alawneh, A. Vedavalli, and H.J. Schünemann, An educational game for teaching clinical practice guidelines to Internal Medicine residents: development, feasibility and acceptability, *BMC Medical Education*. **8** (2008) 50. doi:10.1186/1472-6920-8-50.

[25] F. Faiella, and M. Ricciardi, Gamification and learning: A review of issues and research, *Journal of E-Learning and Knowledge Society*. **11** (2015) 13–21.

[26] M.D. Cabana, C.S. Rand, N.R. Powe, A.W. Wu, M.H. Wilson, P.-A.C. Abboud, and H.R. Rubin, Why Don't Physicians Follow Clinical Practice Guidelines?: A Framework for Improvement, *JAMA*. **282** (1999) 1458–1465. doi:10.1001/jama.282.15.1458.

Address for correspondence

Job N. Nyameino, MBChB, MSc. Email: jbngena@gmail.com